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ELECTRICITY MARKETS & POLICY

Influence of Business Models on PV-Battery Dispatch Decisions and Market Value

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Briefing Content

Background and Introduction

Methods and Data

Asset Owner Business Models & Empirical Dispatch Characteristics

PV-Battery Market Value

Influence of Business Models on PV-Battery Hybrid Value

Berkeley Lab's Solar-to-Grid report focuses on grid value of *stand-alone solar* systems

Characteristics of Deployed Solar

Utility-Scale (UPV)

EIA Form 860 by Plant (>1 MW)

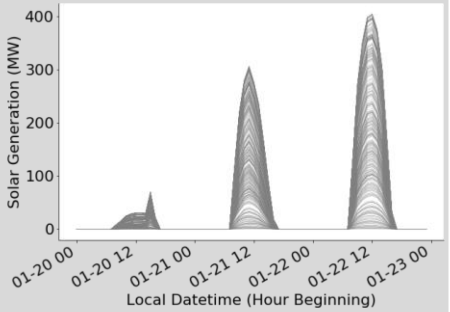
Distributed PV (DPV)

Residential and Non-Residential

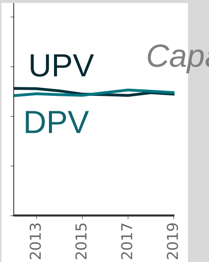
EIA Form 861 by State (<1 MW)

Hourly Solar Generation Profiles

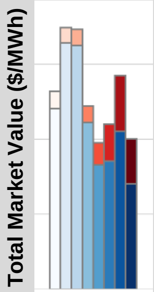
Solar Generation at Individual Plants



Contribution to Reliability



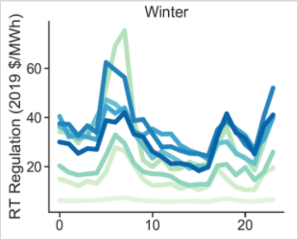
Market Value

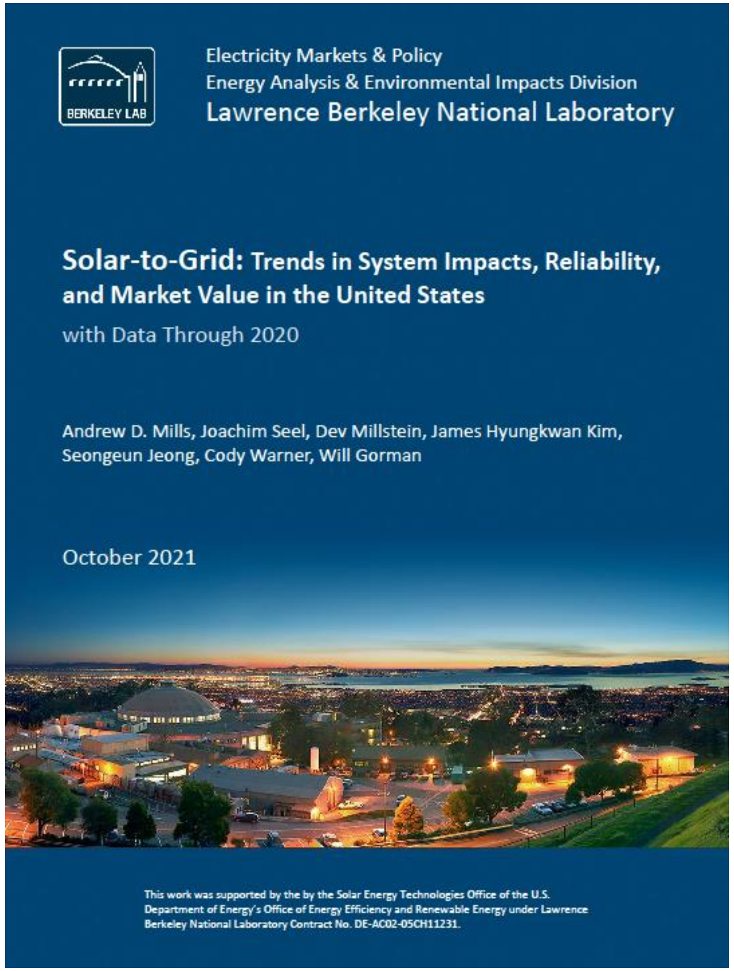


Capacity and Energy Value

Bulk System Impacts

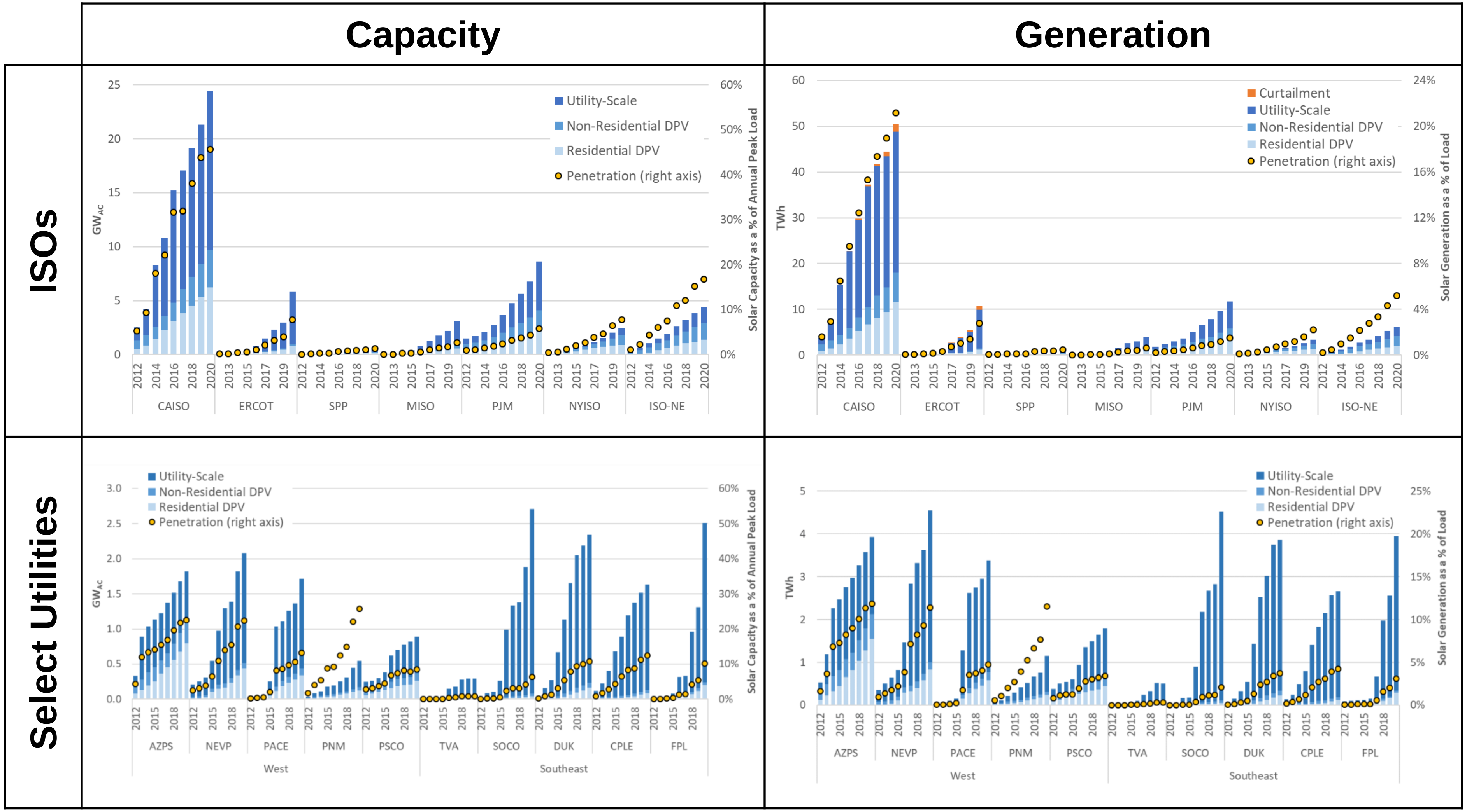
Regulation Prices





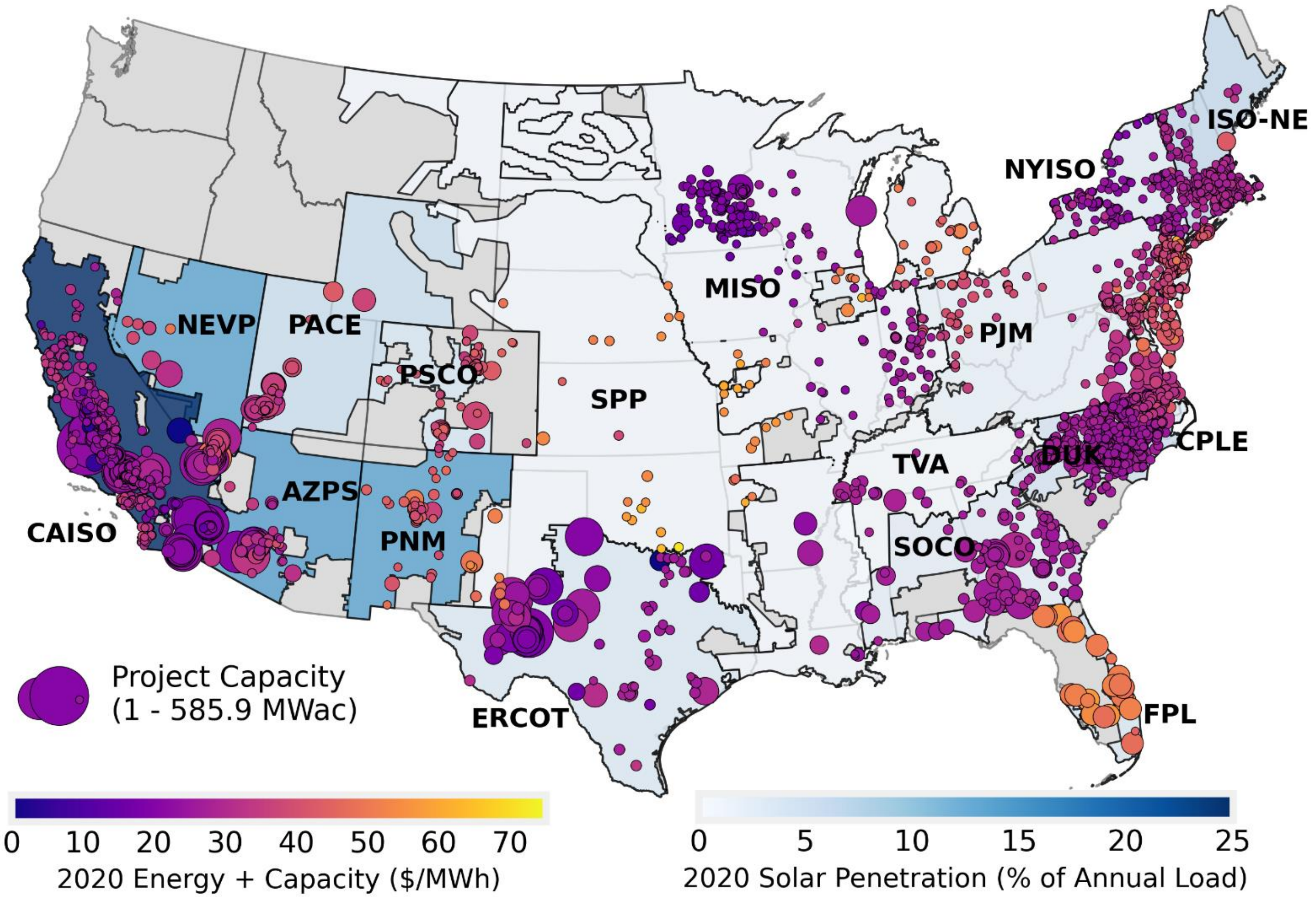
https://emp.lbl.gov/renewable-grid-insights

Solar's effects are greatest in CAISO, but deployment accelerates elsewhere too



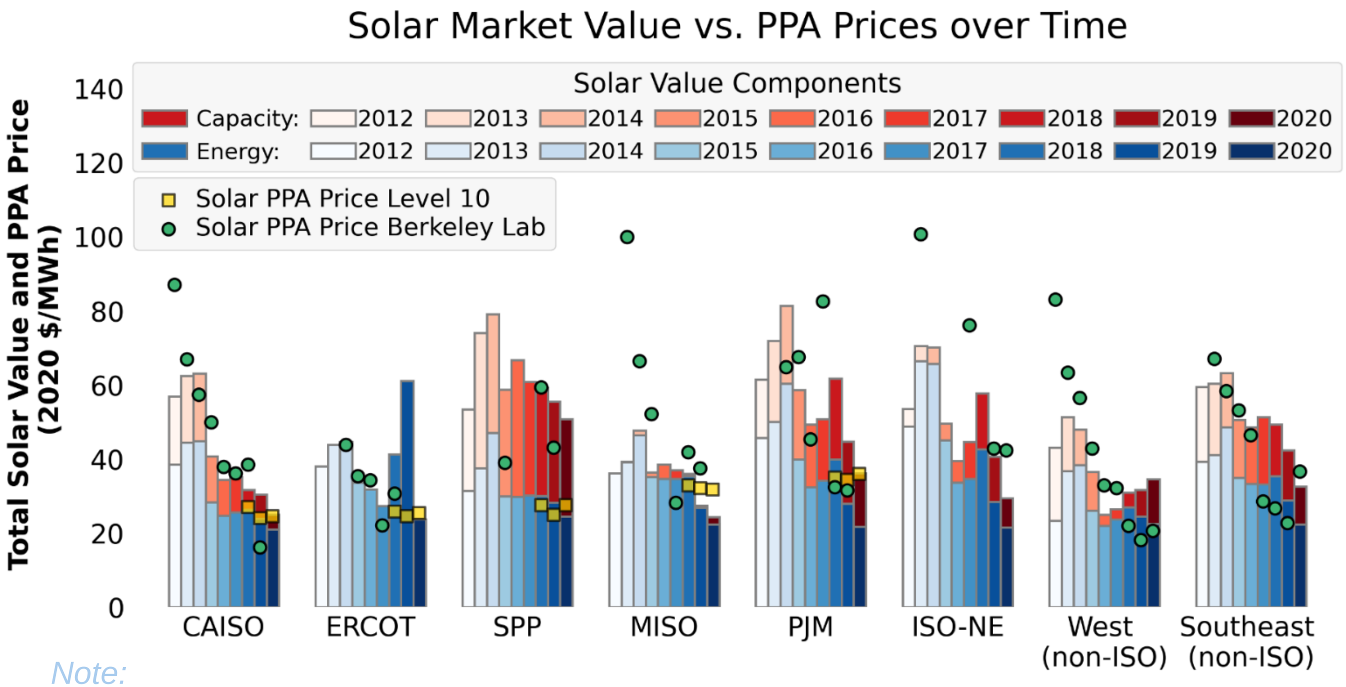
- CAISO represents nearly half the solar capacity of all ISOs, but ISO-NE and ERCOT have rapidly expanding solar market
- Utility-scale solar (>1MW) accounts for the majority of installed solar capacity among all ISOs (even up to 85% in ERCOT)
- Curtailment amounts to 3% of solar generation in CAISO and 6% in ERCOT

Wholesale market value of large-scale solar, by project in 2020



- Value estimates of 3400+ large-scale solar projects (>1MW)
- Bubble size indicates capacity of project, bubble color indicates the combined energy and capacity value, and BA background shading indicates total solar penetration (across distributed and large-scale sectors)
- Solar's value varies between and within regions (for example, western ERCOT has lower solar values than eastern ERCOT, while ISO-NE shows little variation)

Solar value has declined, but falling costs have kept pace, more or less maintaining solar's competitiveness



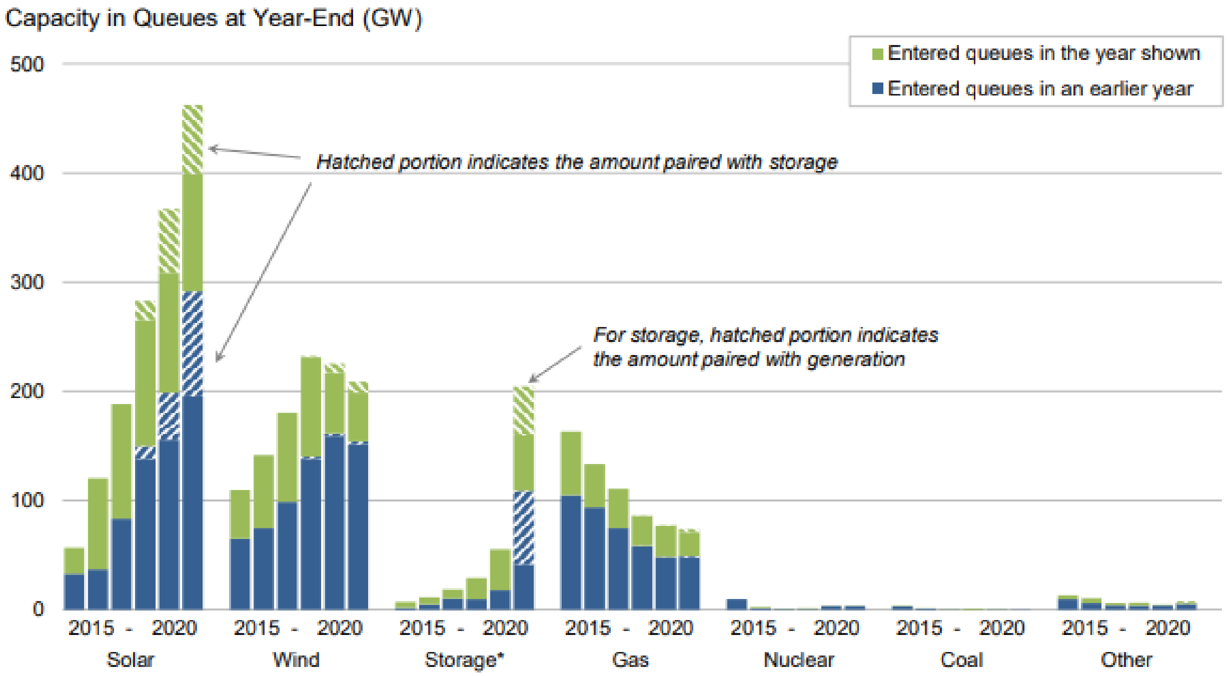
Note:

- *Berkeley Lab's PPA prices are the generation-weighted average levelized PPA prices in real $ by execution date*
- *Level 10 PPA prices represent only the 25th percentile of all offers by offer date*

- The regional solar value is the generation-weighted average value of all distributed and utility-scale solar generation in a given balancing authority
- The energy value makes up the bulk of total market value, but capacity value is significant in eastern markets in particular and accounts for much of the variation between BAs
- Fluctuations across years mostly reflect fluctuations in wholesale power prices (ERCOT 2019), but also increasing solar penetration (CAISO)
- Solar's PPA price have declined over time (falling Capex and Opex, increasing performance and longer design life)
- PPA prices have increased in some markets in 2020 due to supply bottlenecks brought by the Covid pandemic, interconnection delays, and permitting challenges

Hybrid plant capacity is increasing, but assessment of market value using empirical data remains scarce

- Hybrid power plants are being deployed in part to alleviate solar value decline
- 34% of all solar capacity in interconnection queues at the end of 2020 are proposed as hybrids
- Studies often assume storage is dispatched in response to real-time energy market prices
- But PV-battery business models are diverse and can target many different revenue sources



Sources: https://emp.lbl.gov/utility-scale-solar
https://emp.lbl.gov/publications/queued-characteristics-power-plants

We use empirical data to understand how hybrid plant owners dispatch their batteries

Methods and Data

Definition of market value and storage premium

Energy Value

$$V_{Energy} = \frac{\sum Delivered\ Energy_h * Wholesale\ RT\ Energy\ Price_h}{\sum PV\ Generation_h}$$

- Project-level reported hourly generation
- Real-time energy price from nearest pricing node

Capacity Value

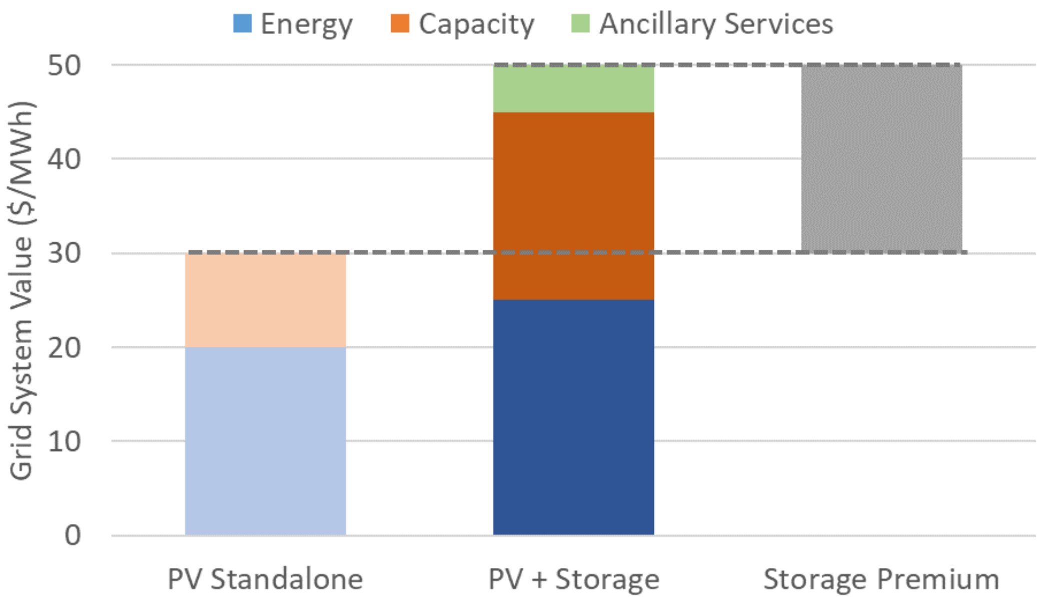
$$V_{Capacity} = \frac{\sum Capacity\ Credit_T * Nameplate * Capacity\ Price_T}{\sum PV\ Generation_T}$$

- Capacity credit either based on plant-level profile or design parameters; varies by month, season, or year
- Capacity prices from respective ISO region; prices vary by month, season, or year
- Denominated here in $/MWh to compare with energy value

Ancillary Services (AS) Value

$$V_{AS} = \frac{\sum AS\ Capacity\ Award_h * Wholesale\ AS\ Price_h}{\sum PV\ Generation_h}$$

- Plant-level reported hourly AS award by service type
- Day-ahead/ Real-time hourly AS price
- Focusing on capacity payments and disregarding mileage payments



We use market value as an imperfect proxy for marginal grid value

It is not the same as private realized value and excludes for example the following value streams:

- No FiT payments, sREC value, (transmission) demand charge offsets, or externalities included in market value.
- Excluding wholesale price effects.

The baseline model : Optimizing battery dispatch for energy value

- In addition to calculating the storage value premium of PV-battery hybrids using empirical metering data, we develop a common “baseline” storage premium
- The “baseline” model uses the empirical PV generation profile but dispatches the paired battery storage to maximize profit based on energy arbitrage
- The baseline profile is subsequently used to evaluate energy and capacity value (we exclude potential AS value)
- The baseline model controls for location and technical design characteristics, allowing us to isolate the value effect of different dispatch strategies (energy-market optimized with perfect foresight vs. a project’s business model)

Assumptions:

- Perfect generation and price foresight
- Using empirical solar generation profile
- AC-coupling between PV and storage
- No charging from grid – only from PV generation
- Degradation rate $5/MWh
- Storage efficiency 94%, inverter efficiency 96%
- POI limit for PV+S at maximum observed export
- Onsite solar energy consumption disregarded during optimization (included in final valuation)

Sample of PV-Battery Hybrids: Hourly metering data from 11 projects

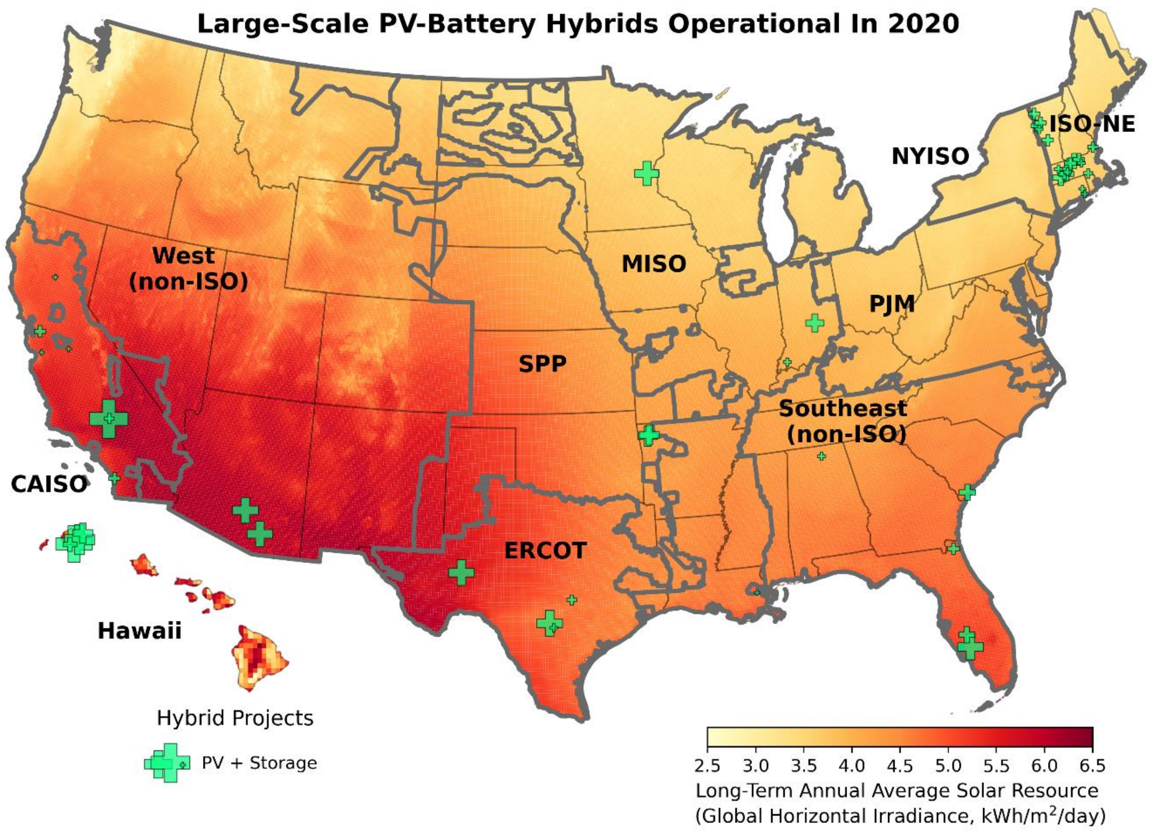
- 46 PV-battery hybrid plants (>1MW_{AC}) operated for all of 2020 in organized wholesale markets

- We conducted 20 interviews with operators and received metering data from 12 plants (dropped 1 plant due to data quality)

- The technical characteristics of the 11 plants are comparable to the full sample, but analytical results may not be representative

Mean PV-Battery Hybrid Characteristics

	Inverter-loading ratio	Battery-PV capacity ratio	Storage duration (hours)
Study sample (n=11)	1.31	0.56	2.68
Full sample (n=46)	1.29	0.78	2.30



- Our sample includes 1 plant in CAISO, 3 plants in ERCOT, and 7 plants in ISO-NE

Asset Owner Business Models
&
Empirical Dispatch Characteristics

PV-battery hybrid business models influence dispatch decisions

Merchant

- **Dispatch signals:** Competitively-set market prices
- **Benefits:** Energy, capacity, and/or AS revenue
- **Ownership:** Independent power producers

Peak-load reducer

- **Dispatch signals:** Regulated peak-load pricing schedules
- **Benefits:** Lower transmission and capacity costs; can be supplemented by AS revenue
- **Ownership:** Load-serving entities

Incentive participant

- **Dispatch signals:** Incentive program rules
- **Benefits:** Feed-in tariff, renewable energy credits (RECs), tax credits, grants
- **Ownership:** Typically independent power producers

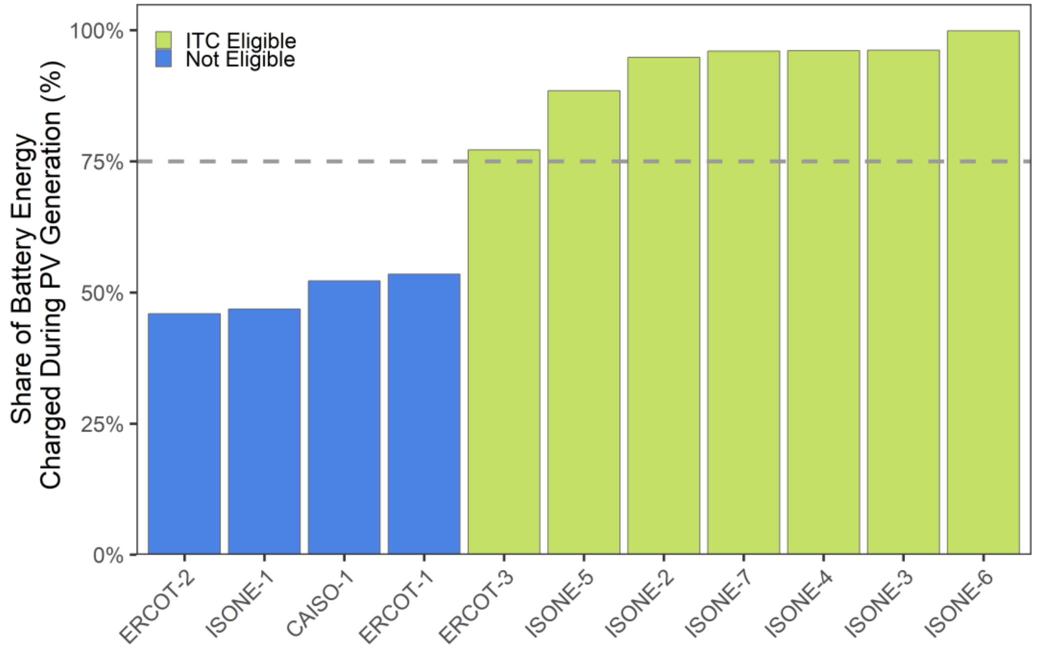
Large end-user

- **Dispatch signals:** Regulated utility tariffs; private operating costs
- **Benefits:** Lower operating costs; resiliency benefits
- **Ownership:** Military bases, manufacturers, oil & gas, penitentiaries

https://emp.lbl.gov/publications/influence-business-models-pv-battery

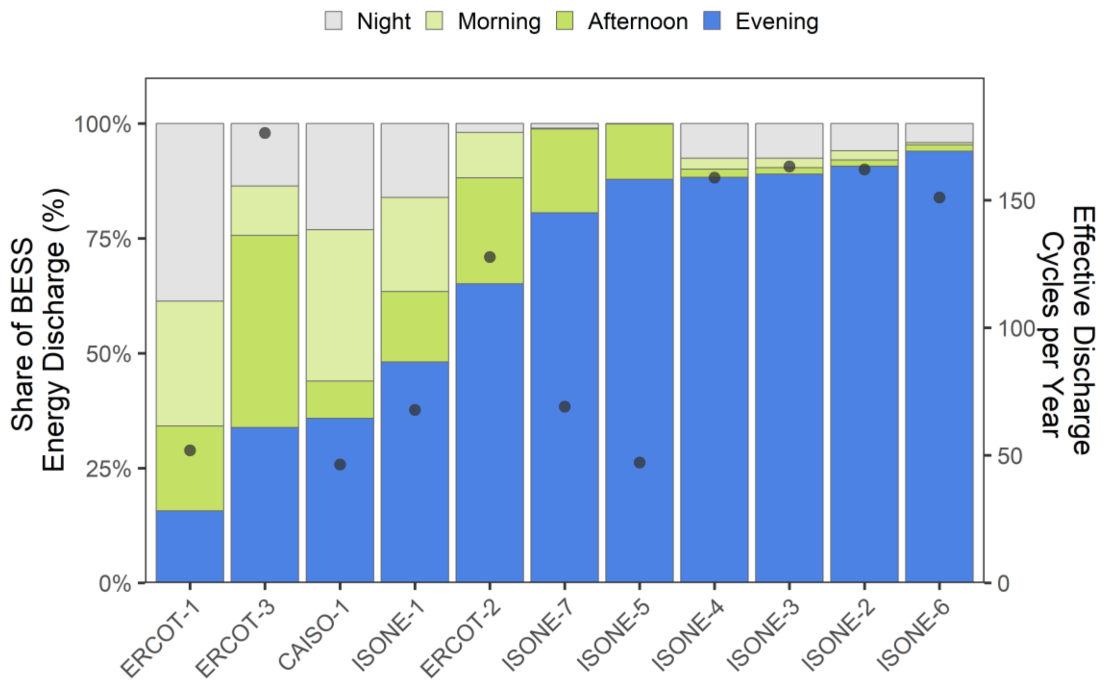
Empirical data shows battery dispatch varies by timing, # of cycles, and amount charged from PV

ITC eligibility of study sample



- Projects not claiming the ITC use more grid electricity to charge the batteries

Timing and frequency of storage dispatch

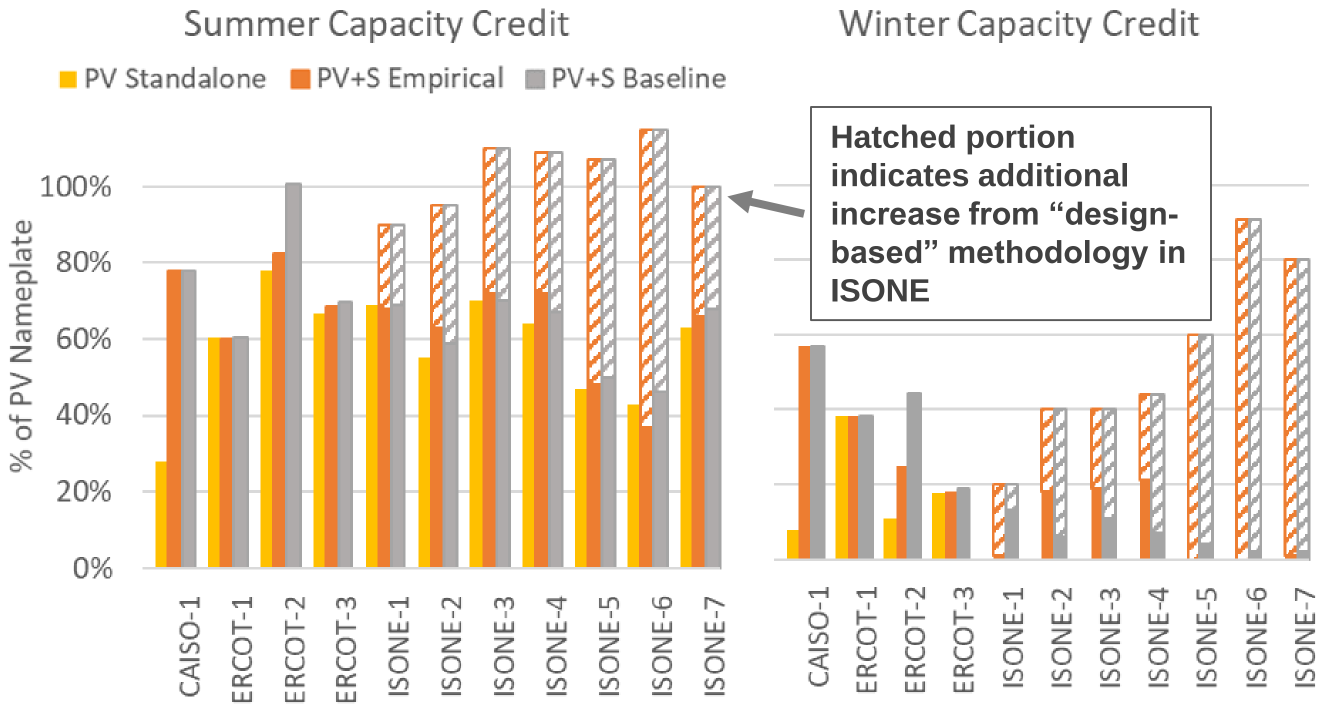


- ERCOT plants discharge in the afternoon, ISONE plants target evening peak hours
- Operational strategies determine how often batteries are cycled

PV-Battery Market Value

Adding battery storage can raise capacity credit, but market rules matter

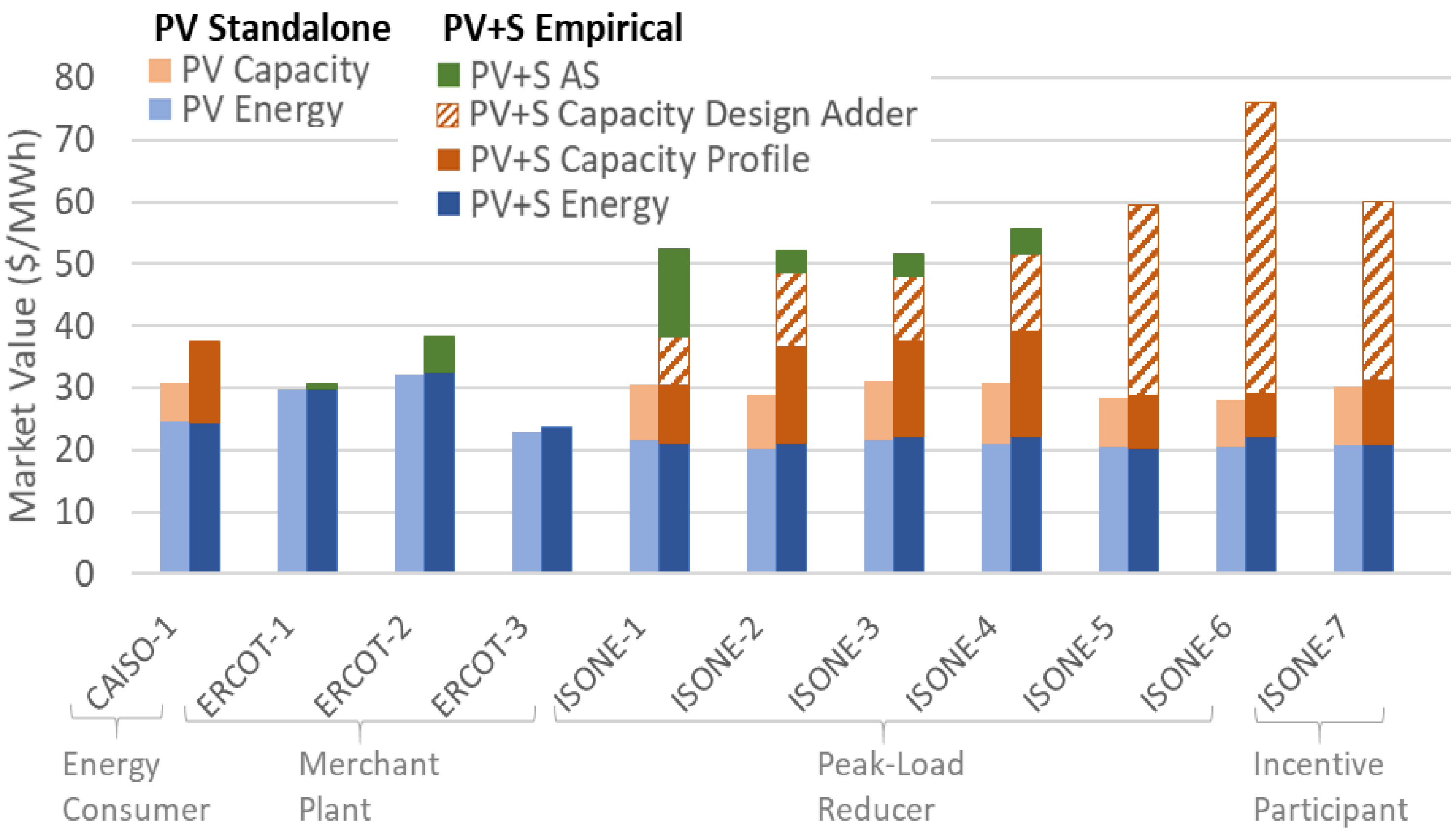
- ISONE assesses credits in multiple ways:
  - ***Profile-based***: median output of the hybrid plant during a daily 4h peak window in the summer and a 2h window in the winter
  - ***Design-based****:* maximum sustained battery discharge over 2h + PV profile-based credit
- CAISO:
  - Maximum sustained battery discharge over 4h +
  - PV credit based on effective load-carrying capability
- ERCOT monitors resource adequacy as average production during the top 20 load hours in each season



- Empirical dispatch-based PV+S credits often very similar to solar standalone capacity credit
- Credits can increase by 20-80% in the summer in ISONE and even 90% in the winter when assessed via design-based methodology

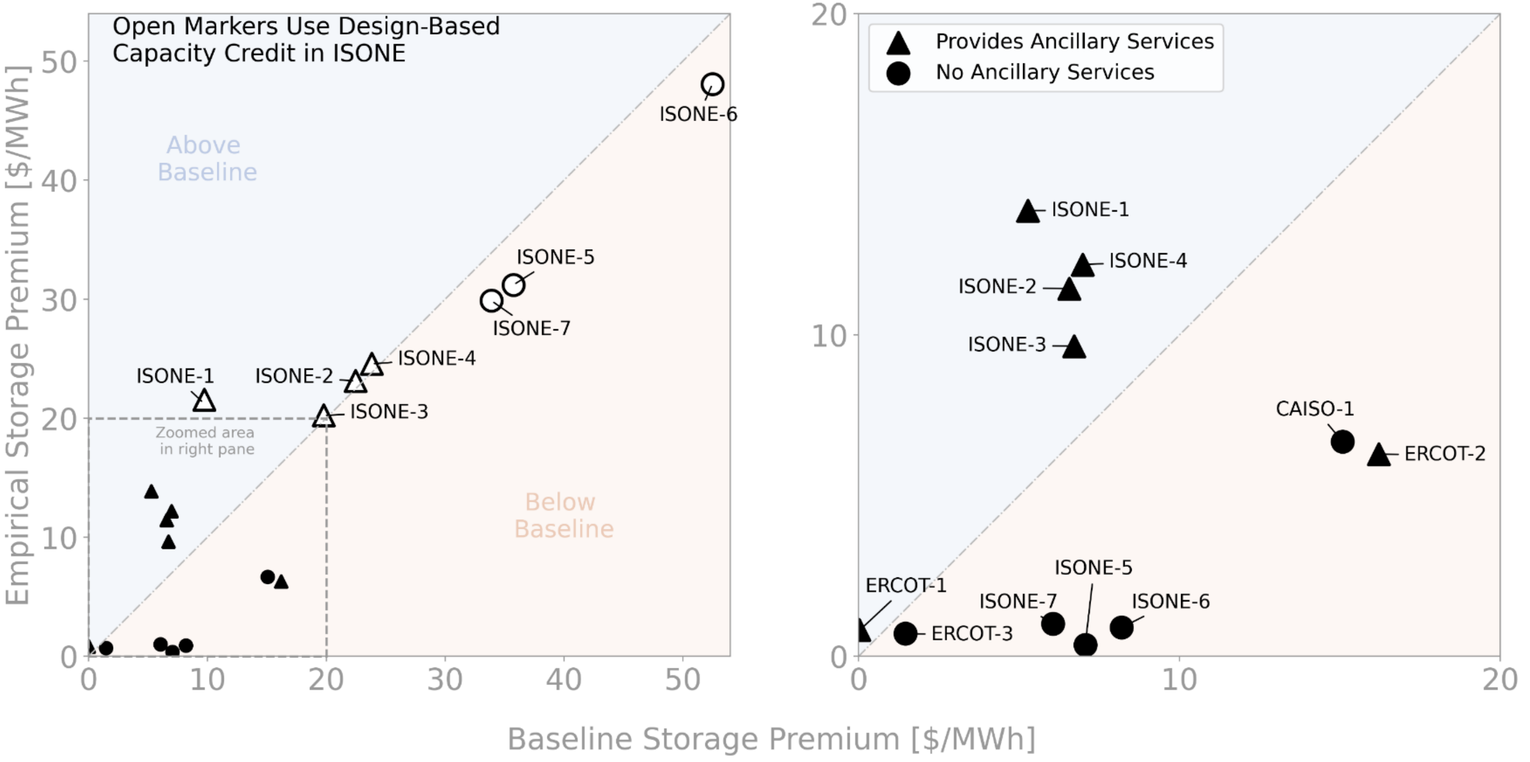
https://emp.lbl.gov/publications/influence-business-models-pv-battery

Empirical PV-battery storage premiums range from $1/MWh to $45/MWh



- Empirical **energy** value premium from adding storage does not exceed $2/MWh
- Key driver of empirical storage premium outside of ERCOT is **capacity** value
  - CAISO-1 doubles its capacity value to $13/MWh by adding storage
  - In ISONE, the profile-based approach yields an increase up to $7/MWh but the design-based method yields an increase up to $54/MWh
- **Ancillary services** provide up to $14/MWh in value

Empirical storage premiums differ from modeled “baseline” storage premiums



- Empirical dispatch differs from modeled baseline (energy arbitrage) and so does the storage premium
- Projects with AS revenue can outperform baseline (▲)
- Some projects do not fully realize their potential market value as operators:
  - Lack perfect foresight of real-time energy prices
  - Confront teething issues in first year of commercial operation
  - Follow other dispatch signals due to their business model

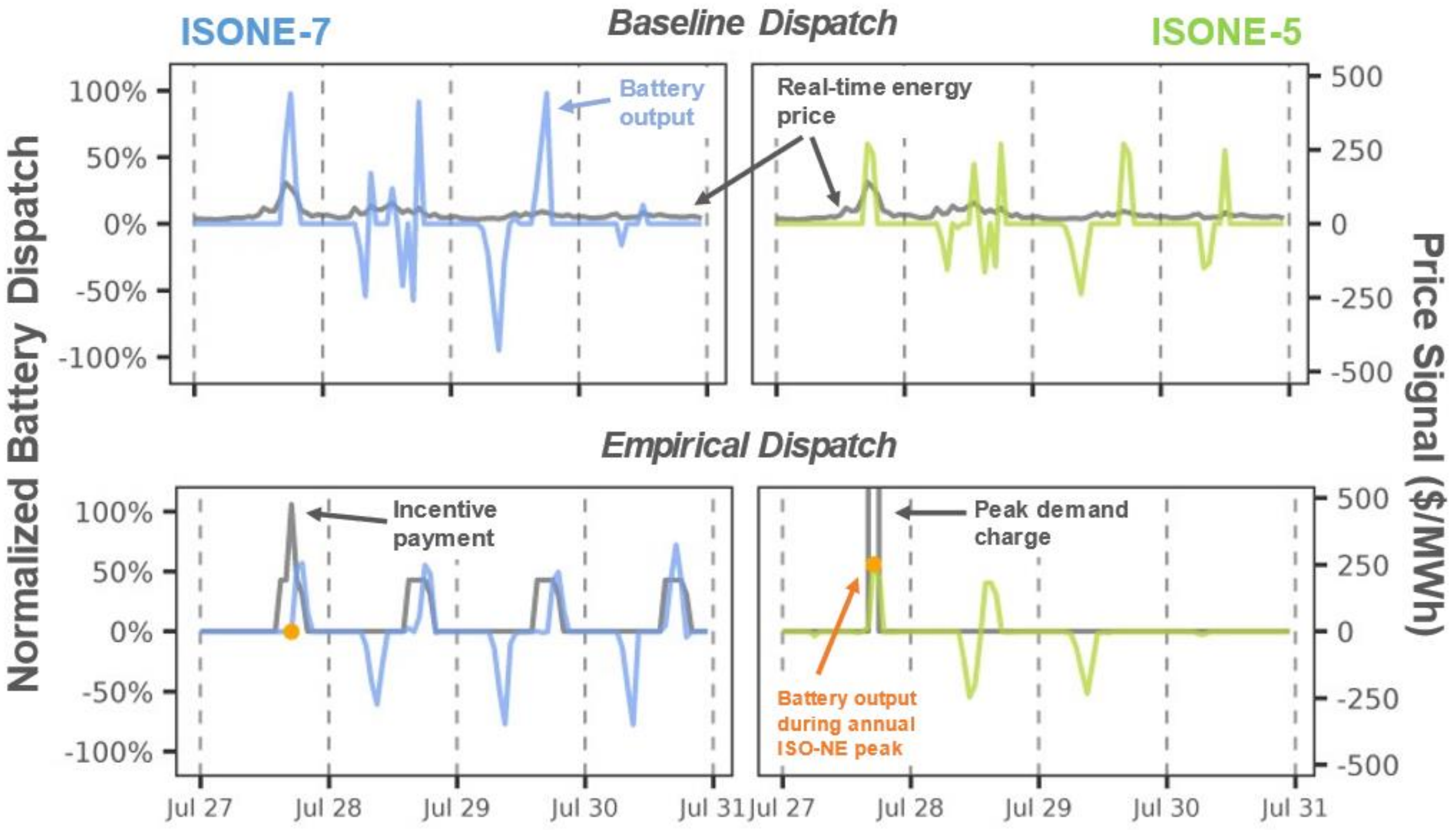
The Influence of Business Models on PV-Battery Market Value

https://emp.lbl.gov/publications/influence-business-models-pv-battery

Empirical dispatch differs from modeled “baseline” due to stronger alternative price signals

- ISONE-5 and ISONE-7 are in moderate proximity to each other and share similar plant characteristics → modeled baseline dispatch is similar

- Empirical dispatch reveals different operating strategies:
  - ISONE-7 is an incentive participant and dispatches to comply with program rules
  - ISONE-5 is a peak-load reducer and targets dispatches to offset peak demand charges

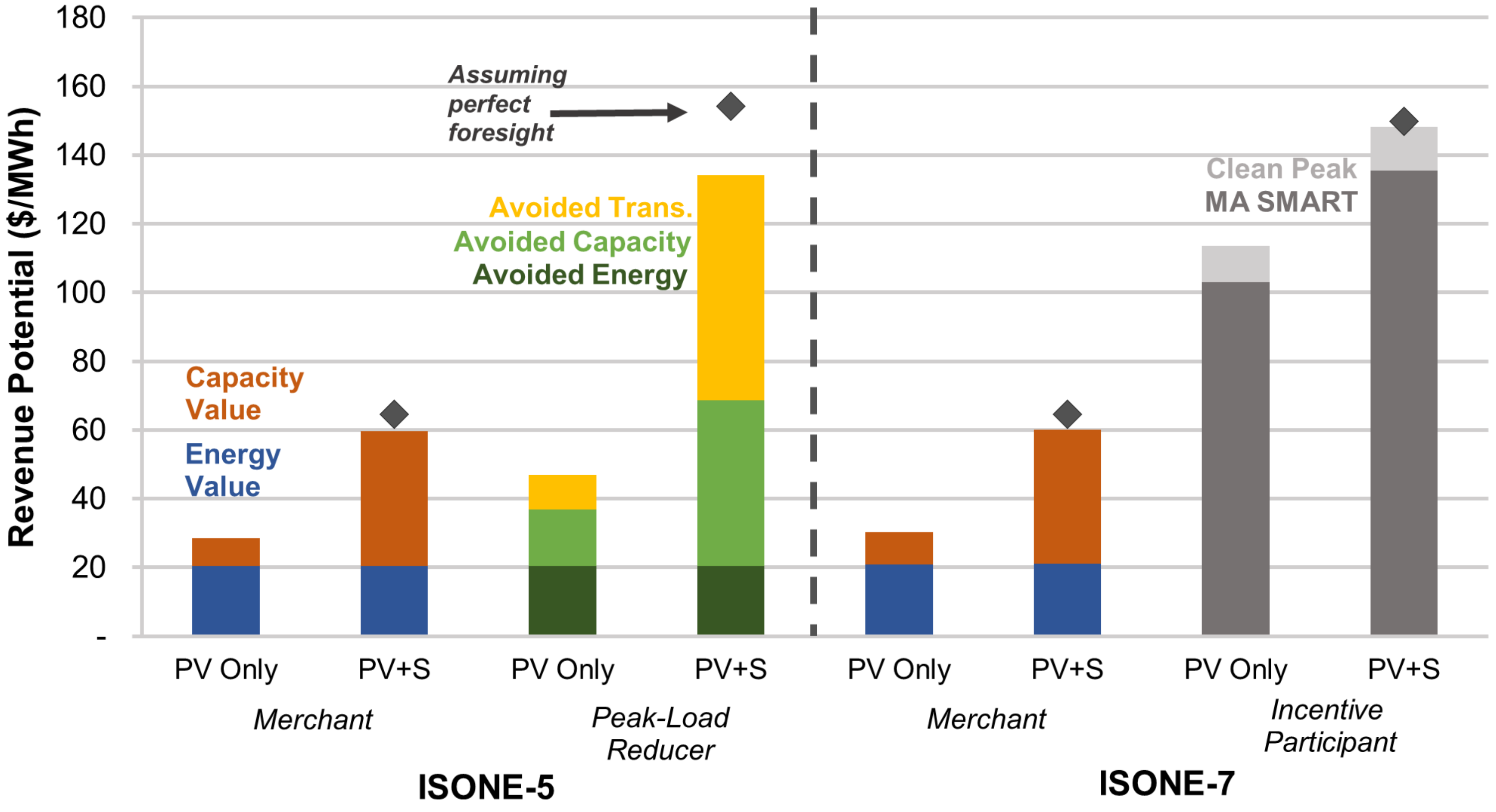


Incentive participant

Peak-load reducer

https://emp.lbl.gov/publications/influence-business-models-pv-battery

PV-battery hybrids earn higher storage premiums or higher total revenue via alternative business models than the merchant model



- ISONE-5 earns as peak-load reducer a ~$85/MWh storage premium, driven by additional avoided transmission charges
  - Perfect foresight can even yield premium >$100/MWh
  - Exceed merchant premium of ~$30/MWh
- ISONE-7 earns as MA SMART and Clean Peak Standard incentive participant a ~$35/MWh storage premium
  - This is similar to the storage premium of the merchant model
  - But total revenue is much greater at ~$150/MWh

Conclusion

- PV-battery hybrid projects dominate the interconnection queues, but little empirical data has been available so far
- Only a minority of projects optimize battery dispatch for wholesale market revenue as merchant plants, majority follow other business models
- Associated operational signals deviate from wholesale market signals but can yield higher private revenue
- Regulators tasked with tariff design and policy makers designing incentive programs should ensure these are aligned with grid needs
- Our study is only a snapshot of 11 PV-battery hybrids in 2020: Storage premiums will evolve (greater deployment, associated market maturity, changing price dynamics), but consideration of operator dispatch decisions will only become more important

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For more information

Visit this project's page for a pre-print journal article and a briefing deck:
https://emp.lbl.gov/publications/influence-business-models-pv-battery

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